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A TECHNIQUE TO CORRECT FOR SAMPLE THICKNESS VARIATIONS FOR USE WITH IDAPS X-RAY RADIOGRAPH ANALYSIS

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16. ABSTRACT The Image Data Processing System (IDAPS) at the Marshall Space Flight Center has been used to analyze radiographs of metal samples to qualitatively and quantitatively map compositional variations across the samples. When the X-ray radiographs are of samples having thickness variations, corrections must be made to accomplish compositional analysis. A correction technique is described for cylindrical samples and is applied to radiographs of SPAR Experiment 74-18. Uncorrected and corrected images are shown.			
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INTRODUCTION

The Image Data Processing System (IDAPS) at the Marshall Space Flight Center (MSFC) was designed primarily for use in the analysis of astronomical data. Specifically, X-ray images of the Sun have been examined using this system [1]. The system was also used in the image analysis of X-ray radiographs of metal specimens for mapping compositional profiles, where the X-ray absorption in the specimens varied according to composition. This work was in support of the Space Processing Applications Rocket (SPAR) liquid mixing experiments (SPAR Experiment 74-18) and is reported in References 2, 3, and 4. Later, the IDAPS was used for other metal system compositional studies. In one case, microphotographs were analyzed [5]. In another case, autoradiographs were studied [6]. The use of IDAPS for all of these compositional analyses is reported in Reference 7.

BASES FOR USE OF IDAPS IN COMPOSITIONAL ANALYSIS

The use of X-ray radiography and subsequent image analysis for compositional analysis of metal specimens, as previously noted, depends on differences existing between the X-ray absorption properties of the sample components. For a sample of a given thickness (Fig. 1) the amount of X-ray energy per unit area which passes through the sample (relative to some initial amount) is proportional to $e^{-\alpha}$, where α is a linear absorption coefficient. That is,

$$I = c_1 e^{-\alpha d} \quad (1)$$

where d is fixed distance, I represents the intensity of the transmitted beam, and c_1 contains factors relating to initial beam intensity. The X-ray

film response for the film density range being used (the "linear" region of the response curve) will be given by:

$$D = c_2 \ln I + c_3 \quad (2)$$

where c_2 is a constant containing information about the specific film being used, D is film density, and c_3 is a constant added because D is defined in terms of relative intensity and is always positive. Combining the two expressions yields

$$D = c_2 \ln(e^{-\alpha d}) + c_3 = -c_4 \alpha + c_3 \quad (3)$$

Since both c_4 and α are positive, the film density D is linearly dependent on α and has a negative slope. As previously noted, this result is for constant sample thickness. If the thickness of a sample is known, an X-ray radiograph theoretically can be calibrated such that film density will be a direct measure of the absorption coefficient of the irradiated sample. For monochromatic X-ray beams, the absorption coefficient will be a unique property of a given element and can therefore be used as an indicator for the presence of that element. For the case of broadband X-ray beams, the absorption coefficient will not be a well-known quantity for a given element. That is, it will depend on properties of the target and the operating voltage of the X-ray tube. When the metals system to be analyzed is sufficiently simple, however, this complexity can be overcome. For a two-component system with the two components having rather widely separated atomic numbers, the X-ray absorption properties for selected tube voltages will be in a useable range even for broadband radiation. A two-component system can be analyzed as shown in Figure 2. Samples of known thickness and of known composition (pure, single metal) are exposed to a source of X-rays concurrently with the exposure of the two-component "unknown" system. The developed film is then analyzed with a microdensitometer (e.g., the IDAPS system input scanner), and film density profiles are generated which can be correlated to sample composition using the reference samples for calibration.

CORRECTION OF DATA FOR SAMPLE THICKNESS NONUNIFORMITY

If the samples to be analyzed are not uniform in thickness, the quantitative use of X-ray radiography and subsequent image analysis becomes more difficult. The SPAR liquid mixing experiments, for example, involved the

compositional analysis of two-metal systems in cylindrical geometries. To obtain quantitative information about composition, it is necessary to provide corrections for sample thickness variations. If a homogeneous cylindrical sample is considered, it can be seen (Fig. 3) that X-rays passing through the sample will not uniformly expose the film. For a homogeneous sample, the intensity of X-rays reaching the film can be written:

$$I = K_1 e^{-x\alpha_1} \quad (4)$$

where α_1 is a fixed absorption coefficient, x is the film thickness, and K_1 is a constant containing information about the initial X-ray intensity above the sample. The film density will have the same form as equation (2), and substituting the relation for I , we obtain

$$D = K_1 \ln(e^{-x\alpha_1}) + K_3 = -K_2 x + K_3 \quad (5)$$

where, again, K_3 is a constant which assures that D will remain positive and K_2 contains K_1 and information about the response of the film being used and about the X-ray absorption characteristics of the sample material. The result, then, is that the film density of a radiograph image of a homogeneous sample is a linear function of sample thickness, decreasing as thickness increases.

For a cylindrical sample (homogeneous), the film density of the resultant radiograph, as a function of position across the sample, has the form shown in Figure 4. This film is then scanned by the IDAPS scanner (a visible light device, essentially a microdensitometer). The resultant gray scale values (GSV, numerically 0 to 255) as a function of sample position will have the form shown also in Figure 4. To calibrate for direct reading of composition in terms of GSV, the desired correction for sample thickness variation will transform the GSV versus position curve to a straight line. The required correction for geometry (for the homogeneous cylinder) is shown in Figure 5. Since the GSV was determined to be a linear function of sample thickness, the correction factor will have the form

$$F = \frac{1}{\sin \theta} A$$

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where

$$\theta = \arccos \frac{x}{R} ,$$

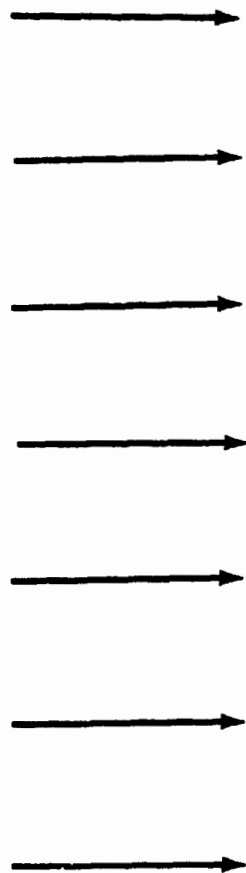
R is the sample radius, x is the distance out from the sample center of the point at which the correction is applied, and A is a number between 0 and 255, since the IDAPS system can only perform manipulations of GSV represented data. To fit the picture size (of the SPAR samples) as encoded and displayed by the IDAPS system, this array will be approximately 100 rows $\times$ 320 columns. The 100-element column contains the F correction factor; that is, x varies across that dimension. The 320 element rows represent the distance parallel to the cylinder axis. All elements in a given row are equal and have values defined by F. Since x goes to R at the sample edges, across x/R goes to 0 degree and 1/sin degree becomes very large. This requires that the correction matrix be terminated at some values of x/R. For this study, x = 0.92 R was chosen; consequently, most of the sample was corrected.

The correction operation, which is shown schematically in Figure 6, is accomplished operationally by constructing the correction array on an IBM 360 compatible tape and then entering into the IBM 360 using IDAPS. The correction multiplication process can then be carried out using IDAPS standard procedures. The multiplication process between the data file, stored as GSV, and the correction file, also stored as GSV, will result in a corrected array having data points out of the 0 to 255 GSV range. An automatic scaling operation is used to bring the corrected array into the 0 to 255 range so that it can be displayed and analyzed. Figure 7 shows GSV versus position for a slice across a radiograph of a cylindrical sample (uncorrected). Figure 8 shows how geometry correction affects the GSV versus position slice. Figure 9 is an uncorrected radiograph of a bimetal sample for SPAR I. Figure 10 is the corrected version of the same radiograph. It may be noted from the histograms appearing below each radiograph that the peaks representing the distribution of GSV are much sharper for the corrected radiograph than for the uncorrected radiograph. This is due to removal of sample thickness dependence.

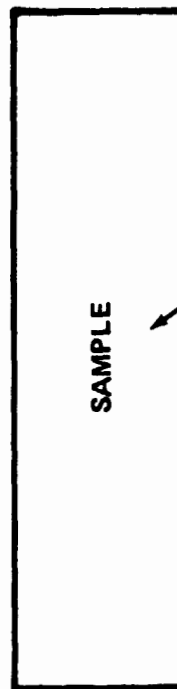
SUMMARY

It has been shown that the IDAPS system can be used for quantitative compositional analysis of the two-component metal system through the use of X-ray radiography. It has further been shown that corrections for variation in sample thickness can be made. The correction procedure for a cylindrical sample has been demonstrated and a corrected radiograph shown.

X-RAY BEAM



SAMPLE



X-RAY FILM

FOR SAMPLE OF UNIFORM THICKNESS,
FILM DENSITY WILL VARY
WITH MATERIAL X-RAY ABSORPTION
COEFFICIENT

Figure 1. X-ray radiography of sample of uniform thickness.

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X-RAY BEAM

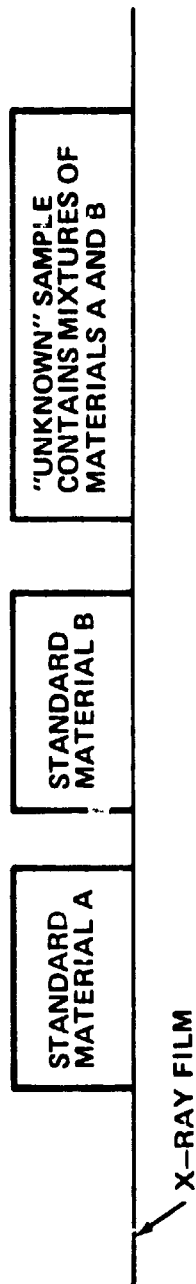
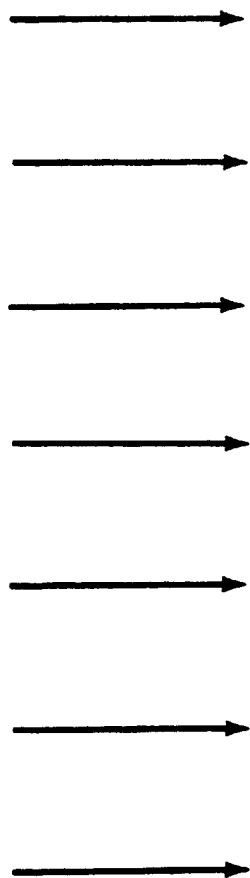


Figure 2. Radiography for quantitative compositional analysis — uniform thickness samples.

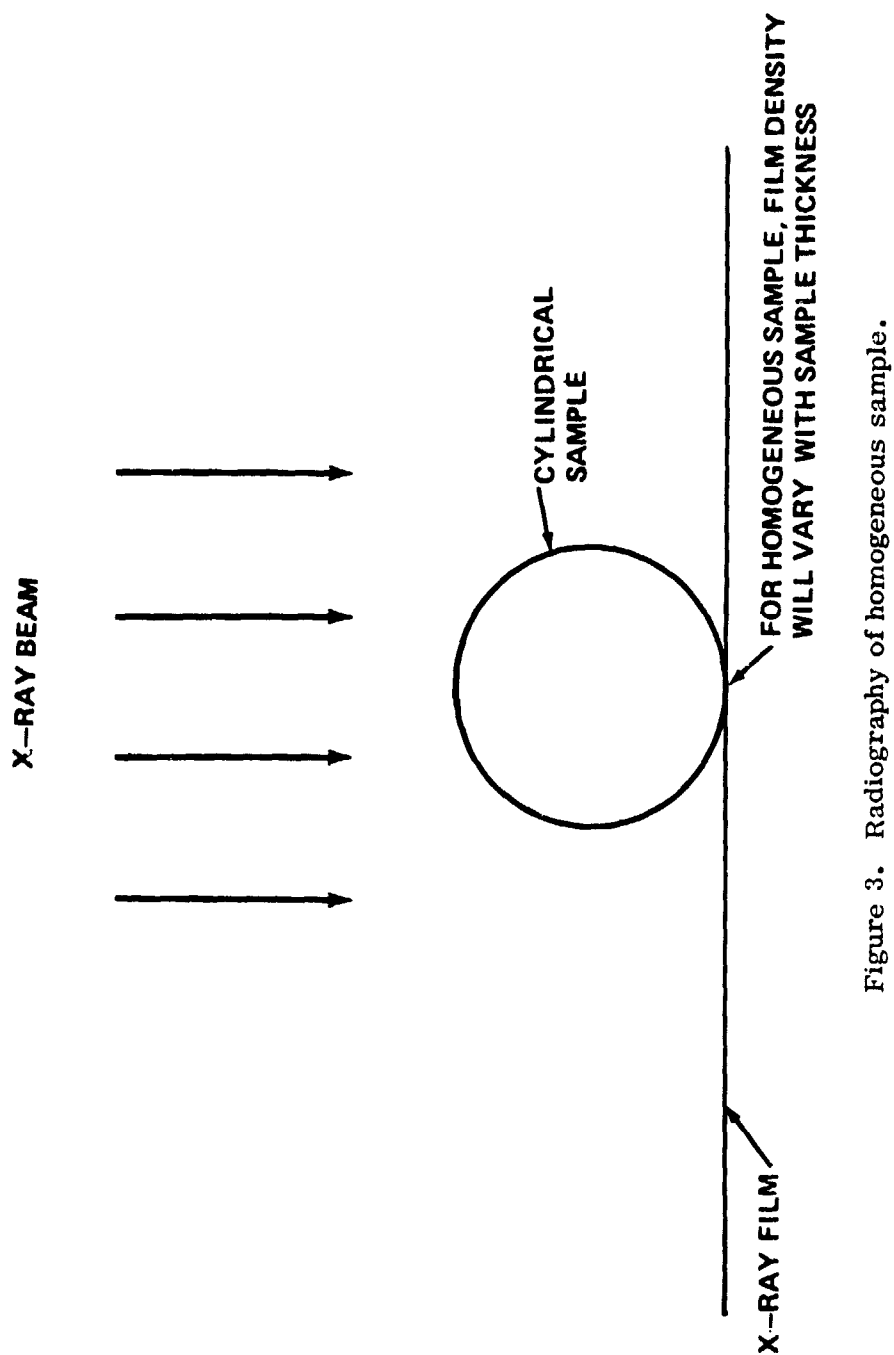


Figure 3. Radiography of homogeneous sample.

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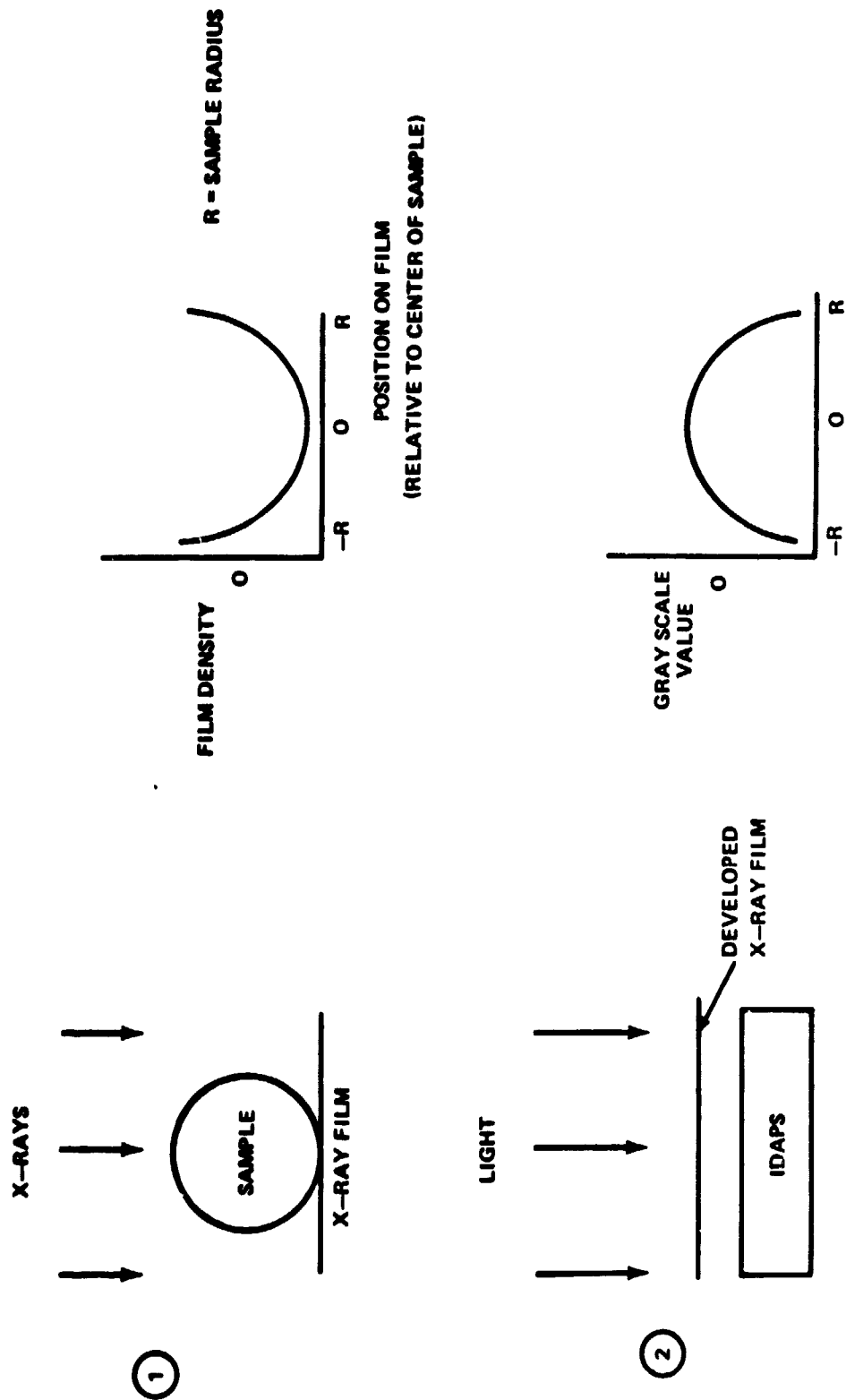


Figure 4. Exposure and analysis for homogeneous cylindrical sample.

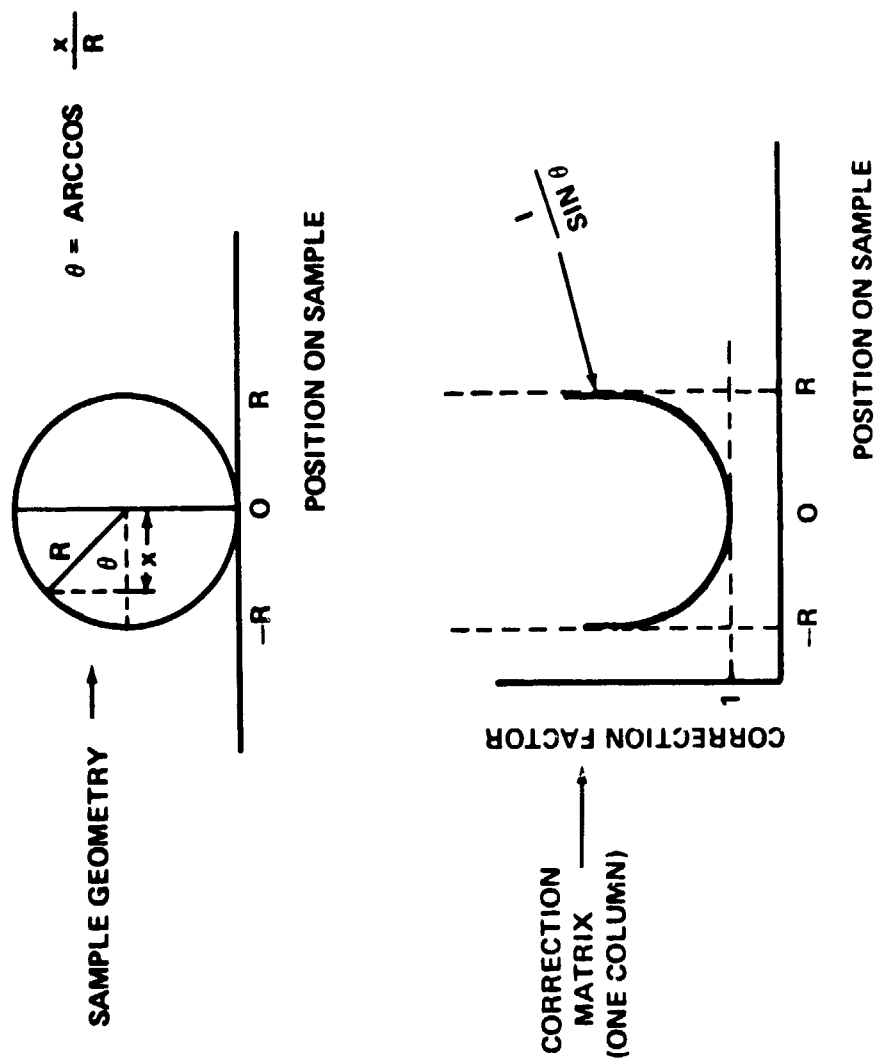


Figure 5. Correction factor for cylinder.

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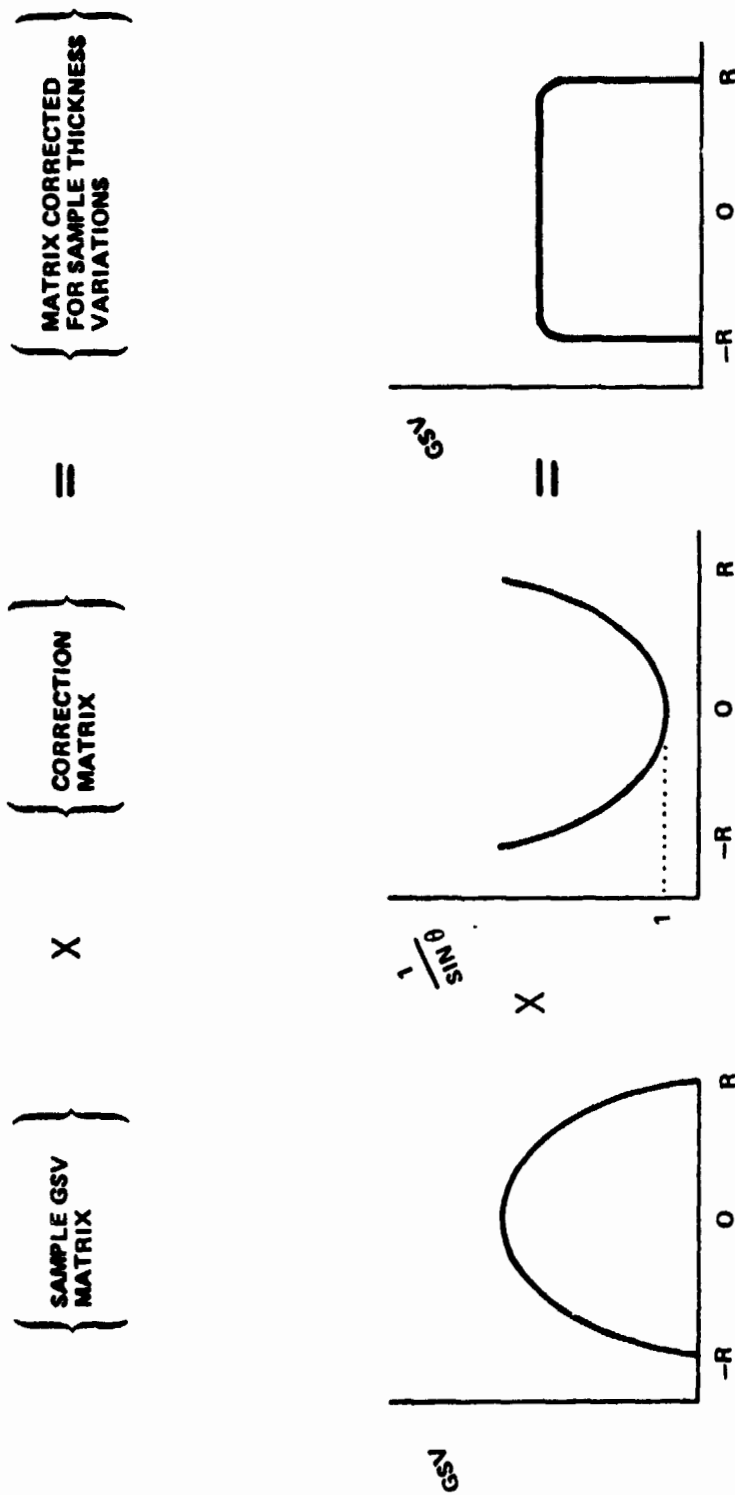


Figure 6. Correction technique.

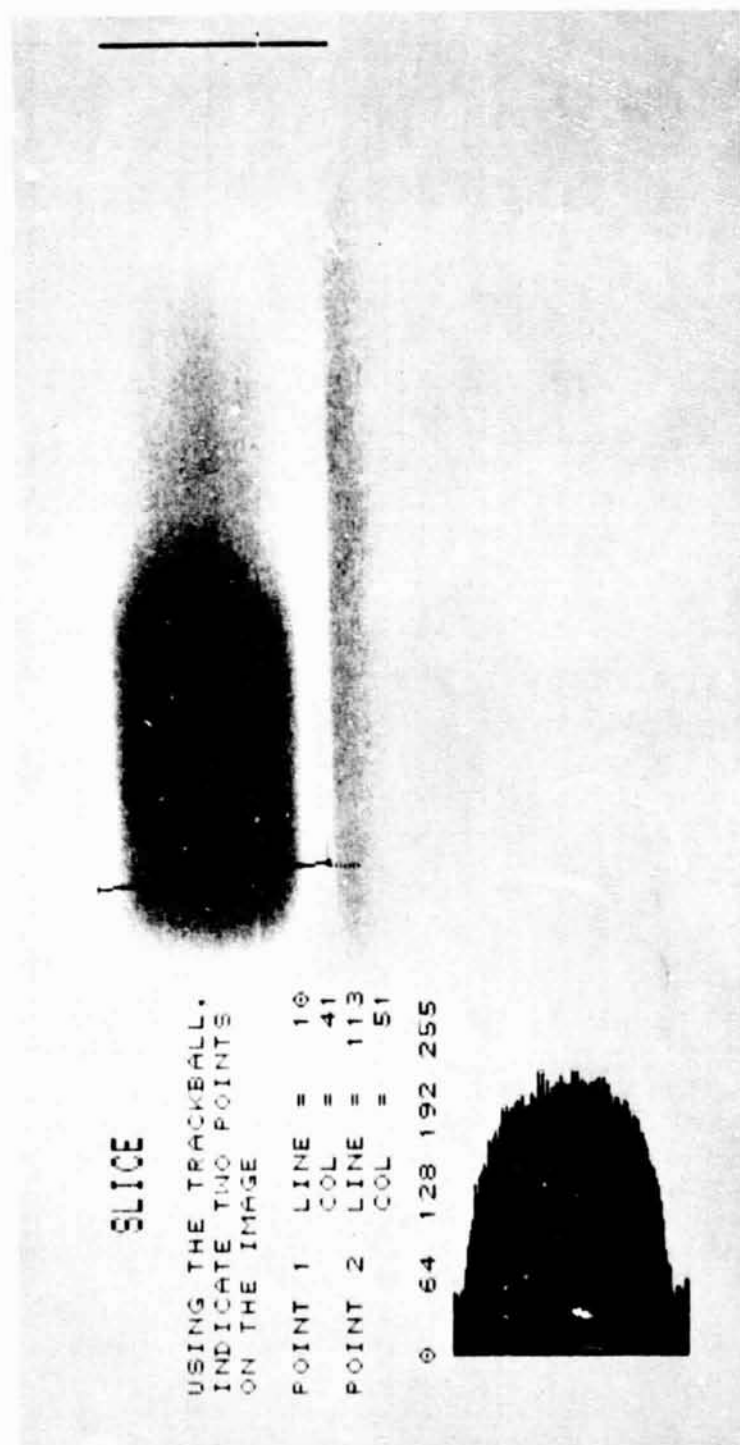


Figure 7. GSV slice — uncorrected.

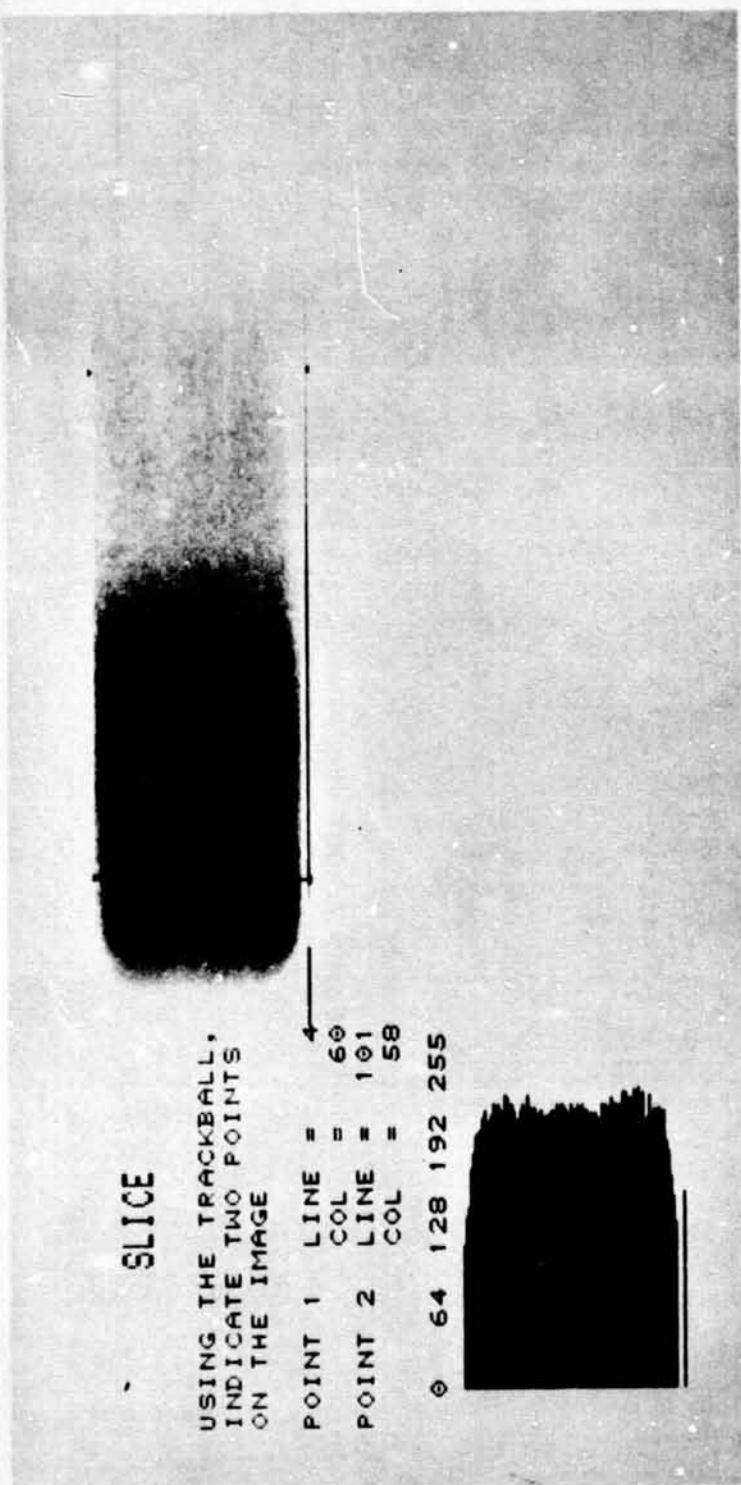


Figure 8. GSV slice — corrected.

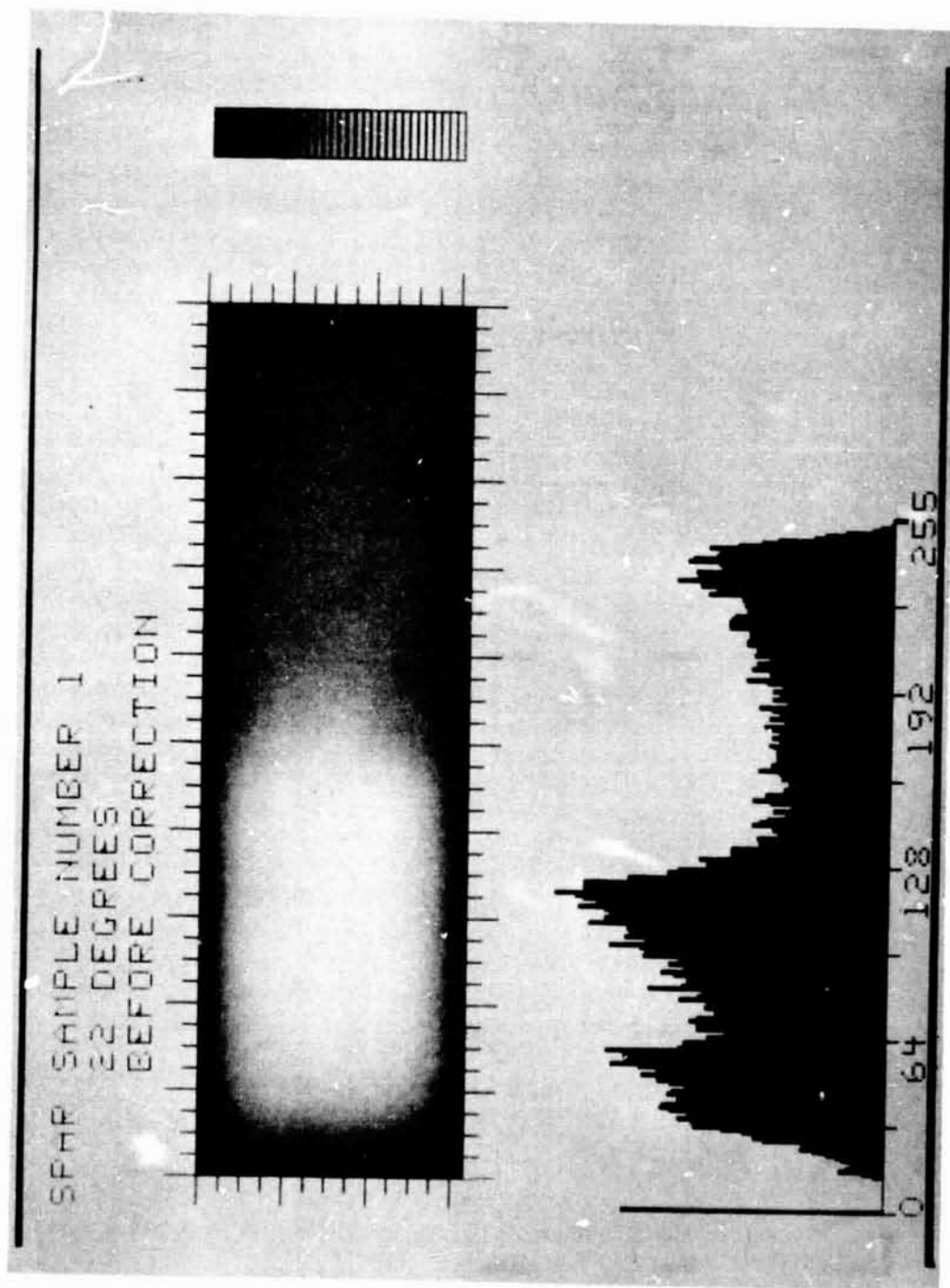


Figure 9. Radiograph of SPAR sample — uncorrected.

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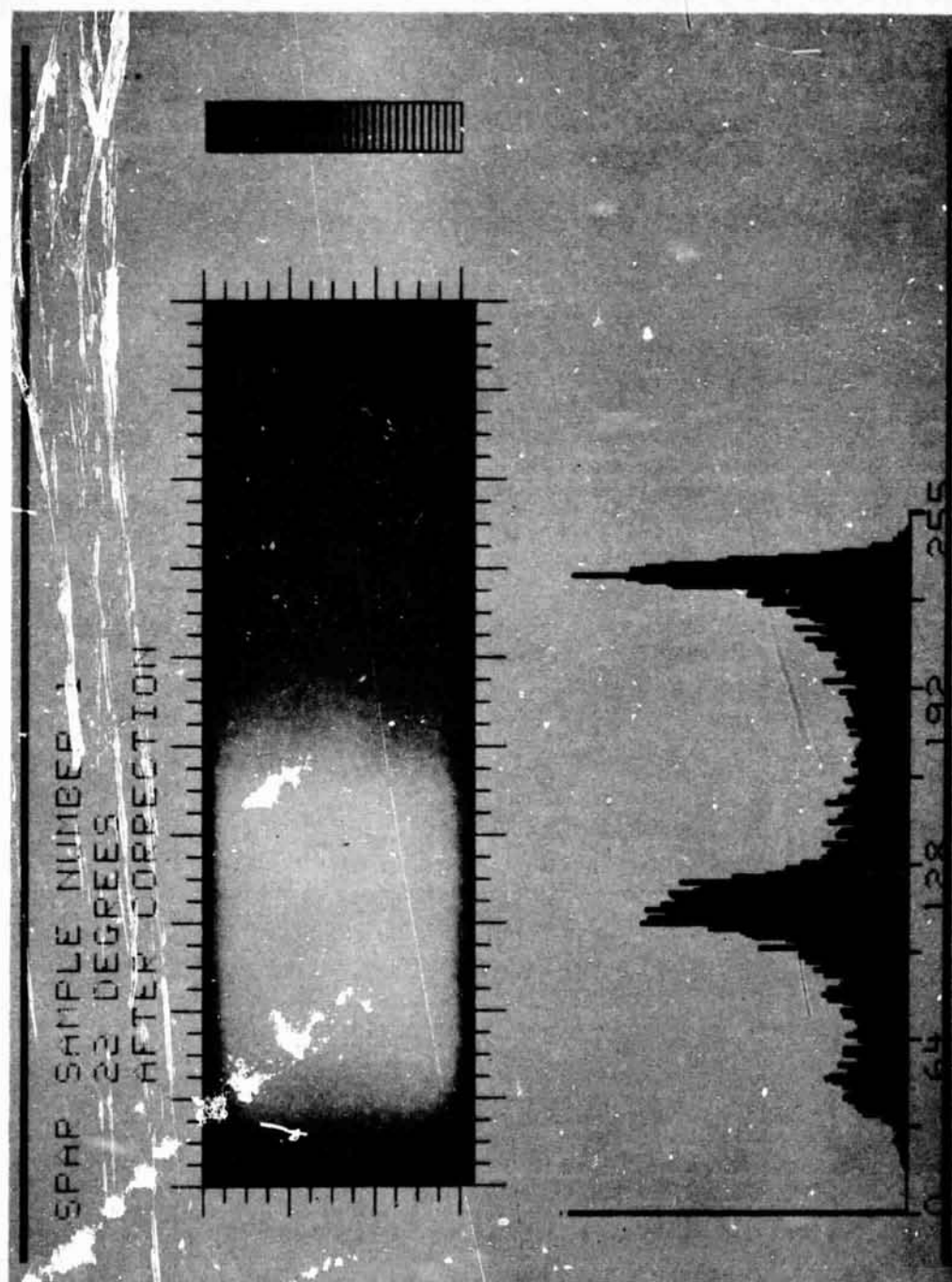


Figure 10. Radiograph of SPAR sample — corrected.

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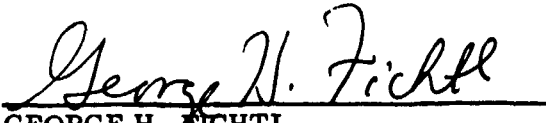
APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.


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